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Rootstock influence on performance of different citrus scion cultivars: A review

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Citrus is one of the most important fruit crop of Pakistan in terms of area and production. Pakistan ranks 7th according to area and 13th according to production. While comparing with leading citrus producing nations like Brazil, USA, China and Spain, citrus production of Pakistan is far behind and increasing at an average annual rate of only 5%. Brazil holds the 35% share in total citrus production of world while share of Pakistan is only 1.46%. Citrus cultivars are propagated asexually through grafting and budding on specific rootstocks. Rootstocks play very important role in Citriculture industry and decide success or failure of citrus cultivation. Under a specific and uniform set of climatic and soil conditions, citrus rootstocks tend to vary in their compatibility with a specific scion cultivar. The rootstocks have significant influence overall growth of tree including vegetative growth, mineral uptake, physiological performance of scion cultivar and reproductive growth of scion cultivars. The role of rootstocks in manipulating or improving the performance of citrus scion cultivars has been discussed in present review.
Keywords: Citrus, rootstocks, physiology, vegetative, reproductive.

INTRODUCTION

Citrus (*Citrus sinensis* L.) holds the key position in world fruit industry, being grown on a large scale in tropical and subtropical regions around the globe. Major production area for citrus is concentrated between 40˚ North and 40˚ south of equator. Citrus belongs to family Rutaceae, havitng sub family Aurantioideae and further represented by 28 genera in the tribe citreae (Swingle, 1967; Niran and Zainab, 2016). While talking about the commercial cultivation of citrus, it is being produced in 53 countries with the production of 137.8 million MT. On the basis of the production, China tops with 29.65 million metric tonnes followed by Brazil with 18.96 million metric tonnes and USA is third with 10.01 million metric tonnes (FAO, 2021).

Citrus holds the key position in horticulture industry of Pakistan. Citrus is being significantly grown in many areas of Punjab *i.e.* Sargodha, Faisalabad and Toba Tek Singh. These districts of central and upper Punjab contributes the maximum share in total citrus production of Pakistan. The share of lower Punjab and other provinces of Pakistan is low in production. (Ateeq *et al*, 2023) In citrus global scenario, Pakistan ranks 7th according to area and 13th according to production. While comparing with leading citrus producing nations like Brazil, USA, China and Spain, citrus production of Pakistan is far behind and increasing at an average annual rate of only 5%. Brazil holds the 35% share in total citrus production of world while share of Pakistan is only 1.46%. In Pakistan, the area under citrus growing is about 192832 hectares and total annual production is 2395550 tonnes (FAO, 2021). The world citrus industry is dominated by sweet orange with 61.18 per cent contribution followed mandarin with a share of 22.12%, lime and lemon with a share of 11.4 % and rest of 5.5 % is contributed by grapefruit and other cultivars of citrus family. Mandarin fruit are relatively small with a tender peel and do not store or ship well. Trees tend to over-bear, which contributes to biennial bearing. All the important phenomenon in a citrus tree such as leaf mineral contents, vegetative performance, bearing habit and reproductive behavior can be significantly influenced by different rootstocks (Castle, 1980, 1987)

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In subtropical Mediterranean climate specifically and all over the world generally, there are various less familiar species of the genus Citrus which are being cultivated there since antiquity. Acclaimed bioactive value, delicious taste and attractive appearance are the major reasons or the popularity of citrus fruits (Liu *et al*., 2015). Talking about worldwide production of citrus China stands at top followed by Brazil and USA. According to United States Department of Agriculture report, in 2016, major exporters of citrus fruits (oranges, mandarins tangerines and grape fruits) were South Africa (1,867 thousand tons), Egypt (1200 thousand tons), China (913 thousand tons), United States (872 thousand metric tons) (FAO, 2021).

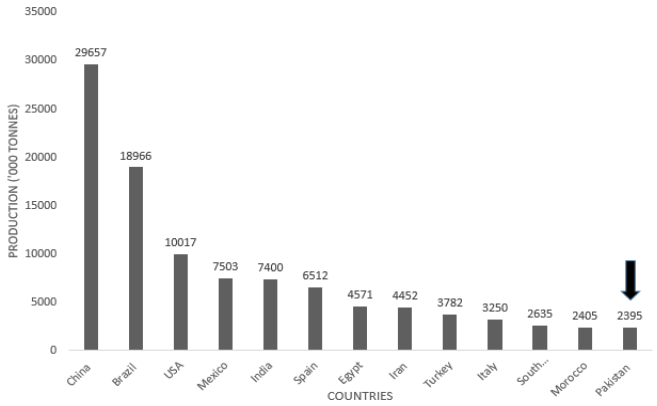

Figure 1. Worldwide citrus production (FAO, 2021).

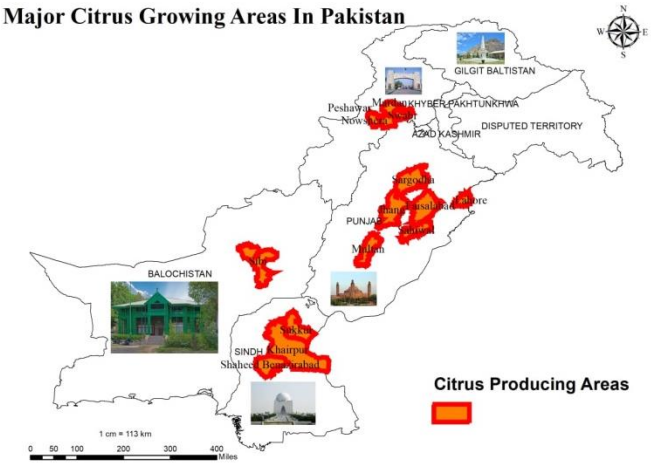

Figure 2. Citrus growing areas of Pakistan.

In Pakistan, 90% of the total citrus is produced in Punjab Province. Sargodha district in Punjab province is considered as hub for citrus production by producing 70 % of total citrus production in Punjab (Ashraf *et al*., 2012). Citrus is being cultivated in other districts of Punjab such as Toba Tek Singh, Faisalabad, Lahore and Gujranwala. Nowshera, Peshawar and Mardan are the major citrus growing areas in Khyber Pakhtunkhuwa province, while in Sindh province citrus production is concentrated in Nawabshah, Khairpur and Sukkur. Baluchistan province has minimal share in overall citrus production. Mekran and Sibbi districts has some potential for citrus production. Kinnow mandarin and Feutrell Early are the major citrus varieties which are grown in Punjab province and accounts for 86 % of the total citrus growing area (GOP, 2021).

Insight about Rootstocks: In the pursuit of importance of rootstocks, citrus cultivars are propagated asexually through grafting and budding on specific rootstocks for attaining the superior performance of scion cultivars in specific agro climatic regions (Forner-Girner *et al*., 2014). Rootstocks play very important role in Citriculture industry and decide success or failure of citrus cultivation (Salman *et al*., 2022. The rootstocks experiment have been performed out in different citrus growing countries from time to time to achieve one or several varied ends such as tree longevity, better scion vigour, insect-pest resistance, adaptability to a specific agro-climatic region, improved fruit quality and higher yield. Rootstocks, however, have their own merits and demerits for example sweet orange, grapefruit, mandarin and lemon on rough lemon rootstock are large, extremely vigorous and productive among most rootstocks worldwide. However, scion cultivars on rough lemon are very susceptible to frost damage (Castle, 2010). Various scientists have reported the significant influence of rootstocks on leaf mineral contents, tree vigor, bearing habit, yield and fruit quality of mandarins. (Castle, 1980, 1987; Castle and Phillips, 1977). Sour orange, although is an excellent rootstock for areas free of citrus tristeza virus (CTV) but its susceptibility to CTV, particularly of sweet orange on sour orange has greatly restricted its use. Jatti Khatti has been reported to be an ideal rootstock for Kinnow mandarin but it is susceptible to Phytopthora (Savita *et al*., 2012) and salinity (Kakade *et al*., 2014) besides its vigorous behaviour. Genetic potential of selected rootstocks is expressed in terms of plant vigour, modify architecture of plants, enhance nutrient and water use, modify physiological process in plants, regulate antioxidant enzymes, polyphenolase activity and impart resistance/tolerance to various biotic and abiotic stresses. Climate change on the other hand is projected to have significant impacts on conditions affecting citrus industry. To circumvent such crisis and to enhance citrus fruit industry, particularly, Kinnow mandarin which is the future of citrus industry in India needs responsive rootstock(s) for enhanced productivity and tolerance to various biotic and abiotic stresses.

Rootstock Scion Interaction: Under a specific and uniform set of climatic and soil conditions, citrus rootstocks tend to vary in their compatibility with a specific scion cultivar. A lot of trials have been conducted to figure out a specific rootstock for commercial scion cultivars of citrus which could address the all aspects of tree in a positive manner (Tuzcu, 1998). For addressing the various shortcomings of citrus i.e. problems

related to soil, biotic stresses and abiotic stresses, usage of rootstocks has become mandatory. Moreover, rootstocks can also help the growers to meet the demands which are made by consumers such as enhanced fruit quality, early fruit maturity and short juvenile phase of tree (Tuzcu, 2004). In the global scenario Common Sour Orange is used as major rootstock but in recent years, some other rootstocks such as 'Trifoliate', 'Troyer citrange' and 'Carrizo citrange' have also become popular among the citrus growers. There is an increased usage of '*Poncirus trifoliata'* and 'Carrizo' citrange rootstocks specifically in mandarin orchards because of hardy nature of these rootstocks and enhanced degree of compatibility with mandarins (Tuzcu *et al*., 1998). The reason for moving on from sour orange to other alternative rootstocks is its less degree of tolerance to Citrus trizteza virus (Tuzcu, 1998). It has been demonstrated and described by many researchers that there is complex relation between rootstocks and scion cultivars which manipulates the various aspects of citrus tree such as tree vigor, earliness in productivity, yield quality (Tuzcu *et al*., 1998; Tsakelidou *et al*., 2002; Georgiou, 2002; *et al*., 2003; Filho *et al*., 2007). The impact of different rootstocks on overall yield, physico-chemical quality of fruit and tree size of 'Valencia' orange in Florida citrus orchards revealed that 'Sun Chu Sha' and 'Cleopatra mandarin' undergoes best performance over other rootstocks. Speaking of tree survival and fruit productivity of individual trees, the performance of 'Cleopatra mandarins' was particularly good. This rootstock is not used as a commercial rootstock (Hutchison and Heran, 1992).

Effect of rootstock on vegetative performance of scion: The rootstocks have significant influence overall growth of tree including vegetative growth and reproductive growth (Salih and Al-Jeboory, 2023). Vigor of scion cultivar and its resistance to different biotic and biotic stresses is manipulated by rootstocks (Continella *et al*., 2018). All the major vegetative parameters *i.e*. tree height, stem girth, leaf area and canopy volume are affected by rootstocks. In Italy, a trial was conducted to check the effect of different rootstocks and on tree growth and physiology. 'Bitters' and 'Furr' rootstocks were promising because of their positive influence on fruit yield and quality also on agronomic parameters of citrus fruits. These promising rootstocks were introduced to citrus industry of Italy (Filho *et al*., 2007). Similiarly, in another experiment effect of different rootstocks on tree growth and yield of lemon cultivars was investigated, 'Rough Lemon' and 'RLC-4' rootstocks gave maximum tree height and canopy; while, 'Billikichlli' and 'RLC-4' rootstocks gave maximum trunk cross sectional area (Dubey and Sharma, 2016). 'Sour Orange' rootstock gave best results for the vegetative growth parameters *i.e*. canopy and diameter, tree volume, disk tree circumference. Maximum tree height was obtained on 'Carrizo citrange' rootstock, while the trees that were grafted on 'Cleopatra mandarin' rootstock were the shortest in the height (Bassal, 2009). 'Hamlin' was grafted on 'Carrizo citrange' and 'Cleopatra mandarin' rootstocks to observe the effect of these rootstocks on citrus nursery plant growth. It was the rootstock that had a significant effect on the sprout of scion cultivar. Sprout numbers and duration, both factors are influenced by rootstocks (Williamson, 1991). Rootstock have marked effect on plant size, shape, vigour, growth, season of maturity etc. Effect of rootstock on scion vigour has been well documented (Forner-Giner *et al*., 2009; Castle *et al*., 2010).

In the first citrus rootstock study conducted in Punjab (Brown, 1920) mandarin was found to make vigorous growth on Rough lemon, medium on sweet lime and was unsatisfactory on the sour orange and citron rootstocks. On the basis of extensive rootstock trials conducted at Abohar, Sharma *et al.* (2002) reported that trees of Campabell Valencia sweet orange on Carrizo citrange rootstock were most vigorous whereas, those on Kharna Khatta (Sour orange) rootstock were the poorest in growth. Trees of Kinnow mandarin in Abohar, Punjab gave a better performance on Jatti Khatti (Rough lemon) closely followed by Karun Jamir and the minimum growth was on Pectinifera rootstock (Sharma *et al*., 2002). Similarly, Stenzel *et al*. (2003) reported that out of seven rootstocks tried in Londrina, Brazil for Ponkan mandarin, Sunki mandarin on Volkamer lemon showed significant lower plant height than other rootstocks. Likewise, Castle *et al*. (2010) observed the largest trees of Valencia sweet orange on Volkamer lemon and the shortest trees on Swingle citrumelo among twelve rootstocks evaluated. The trees of Sunbrust mandarin in Piracicaba, Brazil gave better performance on Orlando tangelo than on Rangpur lime, Swingle citrumelo and Cleoptara mandarin (Filho *et al*., 2007). Similarly, Bassal (2009) working in Ismailia, Egypt reported that trees of Marisol clementine resulted in maximum plant height on Carrizo citrrange and Swingle citrumelo whereas, the lowest was on Cleoptara mandarin and sour orange among the four rootstocks evaluated.

Ahmed *et al*. (2006) investigated the performance of nine different rootstocks on growth and yield of Kinnow. Out of the nine rootstocks studied, Volkamer lemon, Brazilian sour orange and citrumello 4475 were recommended as reliable rootstock for the citriculture industry of Pakistan. Trees on Jatti Khatti were reported to be the most vigorous and Pectinifera to be the least vigorous. Similarly, Nasir *et al.* (2011) evaluated the response of Kinnow budded on three different rootstocks at Sargodha, Pakistan. They observed vigorous growth with respect to plant height, spread, scion, stock girth and canopy size on Rough lemon rootstock while Rangpur lime proved to be a dwarfing rootstock.

Effect of rootstocks on leaf mineral concentration: For the proper growth and maintenance of plant vigor, presence of adequate amount of macro and micronutrients in plant body is of utmost importance.All of the nutrients present in citrus plant are affected by rootstocks (Taiz and Zeiger, 2002). There is varying amount of nutrients in scion cultivars grafted

on different rootstocks. Less concentration of nitrogen was present in scion bark of Kinnow as compared to nitrogen contents in rootstocks bark, in rootstock bark there was higher amount of nitrogen; however, higher amount of potassium was recorded in scion cultivar as compared to rootstock (Huchche, 1999). Satsuma mandarin when grafted on sour orange and Carrizo citrange, highest leaf nitrogen contents were recorded from Carrizo citrange rootstock while Sour orange rootstock depicted lower levels of nitrogen in Satsuma mandarin (Creste, 1995). Varying amounts of nitrogen, phosphorus and potassium were recorded in 'Red blush'and Ponkan mandarin' when grafted on different rootstocks (Araujo *et al*., 1998; Fallahi and Rodney, 1992)

Wutscher *et al.* (1970) reported that in young grapefruit trees grafted on sixteen rootstocks, there was no significant difference in leaf N and Na on different rootstocks. But B, Mn, P, Zn and Cu content of leaves was affected by different rootstocks. The leaves of Marsh Seedless grapefruit on Rough lemon showed a tendency to accumulate more Na, Cl and B, and less Mg, while Cleopatra rootstock induced greater uptake of Mg Na and B (Economides, 1976; AL-Wailli). leaf analysis of six scion varieties showed that the percentage of Na was essentially the same for sour orange and Cleopatra mandarin rootstocks. With sour oranges, K level was higher than with Cleopatra. In other experiment, Wutscher and Shull (1972) found significant effect of rootstocks on the foliar levels of N, K, Mg, Mn, Zn, Na, Cl and B fourteen years old nucellar Red blush grapefruit, grown on thirteen rootstocks. Differences in the contents of P, Ca, Fe and Cu were non-significant. Leaf Mn was high on Cleopatra and low on Carizzo, Troyer and Morton citranges.

Absorption of water and nutrients from the soil and translocation of nutrients from roots to other plant parts is significantly influenced by rootstock as rootstocks are responsible for the formation of rooting of the plant and proliferation of the roots. Variation in absorption and translocation of various nutrients from the soil may results in differences in many biochemical and physiological processes of the scion cultivar (Fallahi and Rodney, 1992; Georgiou, 2000, 2002; Tsakelidouetal., 2002; Smith *et al*., 2004; Marathe *et al*., 2006). Depending upon agro climatic conditions and soil characteristics, rootstocks can perform differently, and these differences appear as varying performance of scion cultivars grafted on them.

Macronutrients: Different mandarins were grafted on *Poncirus trifoliata*, Sour orange and Troyer citrange and it was found that higher nitrogen contents in leaves of scion cultivar were recorded from *Poncirus trifoliata* and Sour orange. Scion cultivar grafted on Sour orange had lower nitrogen contents (Cassin *et al*., 1976). In another experiment a notable variation was recorded in nitrogen levels of Valencia orange when grafted on three different rootstocks (Heinz and wutsher, 1982). Coorge and Kinnow mandarin were grafted on seven different rootstocks to investigate the capability of these rootstocks to manipulate the nutrient accumulation in scion cultivar. It was observed that nitrogen levels of scion were significantly influenced by different rootstocks. Rough lemon and Sour orange were the traditionally using rootstocks in the world. Various trials have been designed to test the performance of these rootstocks along with other new rootstocks in order to find the suitable substitute to these traditionally using rootstocks. Highest nitrogen contents in scion cultivar were obtained from sour orange while performance of Cleopatra mandarin was also satisfactory in order to enhance the nitrogen levels of scion cultivars (Erdal *et al*., 2008) Kinnow is commercial cultivar of citrus. Effects of different rootstocks have been reported on manipulating different aspects of Kinnow mandarin. Kinnow was grafted on different rootstocks i.e. Carrizo citrange, Yuma citrange, Rough lemon, Citrumello 4475 and Citrumello 1452. Maximum nitrogen levels in leaves of Kinnow mandarin were recorded on Citrumello 4475 and 1452. Due to maximum nitrogen concentration, vigor and canopy volume of Kinnow mandarin was also higher on these rootstocks (Iqbal *et al*., 1999). In another study maximum nitrogen levels were recorded in Kinnow mandarin grated on *Poncirus trifoliata* rootstock. *Poncirus trifoliata* is one of the hardiest rootstocks due to its extensive and well proliferated root system which enables the maximum absorption of nutrients from the soil and ultimately leads to better performance of scion grafted on this rootstock (Araujo *et al*., 1998). Phosphorus is second most important macronutrient being responsible for proper reproductive growth of the plant. Kinnow mandarin was grafted on different rootstocks to check the absorption of phosphate and its translocation from roots to other scion cultivars. Significant differences among the rootstocks were recorded regarding phosphorus contents in the leaves of Kinnow mandarin. Kinnow trees grafted on sour orange rootstocks depicted the highest levels of phosphorus (Fuller and Hilgeman, 1955). Significant variation among the rootstocks was recorded in terms of phosphorus contents in the soil. Cleopatra mandarin proved out to be most vigorous rootstocks by having maximum phosphorus contents in all three scion cultivars. Due to higher phosphorus levels yield and fruit quality of all three scion cultivars was excellent on Cleopatra mandarin. Besides rootstock influence it was also recorded that, there exists a correlation between phosphorus contents in the leaves and the yield capability of tree. Lemon and Kinnow mandarin were grafted on some dwarfing rootstocks such as *Poncirus trifoliata* and its hybrids to check the nutrient uptake in the plants in different rootstocks. Maximum phosphorus uptake in lemon and Kinnow mandarin was recorded on *Poncirus trifoliata* rootstock due to healthy roots system developed by this rootstock (Wallace *et al*., 1981). Potassium is the third most important primary nutrient, required by the plant for the normal functioning. Several physiological processes are catalyzed by potassium. Rootstock manipulate the

phosphorus contents of the scion cultivar when grafted on them. Grapefruit was grafted on different rootstocks to check the influence of different rootstocks on NPK contents in the leaves. Valencia orange proved out to be best rootstock for grapefruit by having maximum potassium contents in the leaves of scion cultivar (Smith *et al*., 1949). Kinnow was grafted on different rootstocks to check the nutrient holding capacity of Kinnow grafted on different rootstocks. It was found that Kinnow mandarin grafted on sour orange rootstock had the maximum potassium contents (William *et al*., 1952). Another experiment was conducted by Shah (2004) who evaluated the performance of different rootstocks i.e. Rough lemon. Concentration of macronutrients was recorded and it was found that Kinnow mandarin grafted on Cleopatra mandarin had the maximum potassium contents while comparing to other rootstocks. Performance of Troyer citrange was poorest of all.

Effect of rootstocks on tree physiology: Physiological frameworks of scion cultivars are also controlled by rootstocks by controlling the concentration of starch, sugars and other phyto-harmones (Morinaga and Ikeda, 1990). Tree growth parameters including CO_2 assimilation, C-photo assimilation transport and carbohydrate distribution, all are controlled by rootstocks. 'Cleopatra mandarins'and 'Forner-Alcaide-13' rootstocks were used in an experiment in which these rootstocks were grafted with 'Navel oranges'. Results revealed that 'Navel oranges' which were grafted on 'FA-13' rootstock showed better photo assimilation rates from leaves to fruits, transporting higher photo-assimilate from leaves to developing fruit and higher CO_2 conductance rate as compared to those grafted on 'Cleopatra mandarin' (Jover *et al.,* 2012). The physiology of rootstocks may vary under similar sets of management practices. Moreover, scion behavior depends in part on the rootstock and induce effects on leaf gas exchange (Gonzalez-Mas *et al*., 2009). The influence of rootstock on leaf gas exchange is taken as a key factor while studying the performance of scion cultivars on different rootstocks. Measurement of physiological parameters and leaf gas exchanges from the tree in rootstock-scion combination is therefore, important for understanding the variation in leaf gas exchange parameters. Rootstocks may influence the chlorophyll contents and relative water content sof scion when grafted on it (Garcia Sanches, 2002). Literature on the effect of different rootstock on RWC content of Kinnow has not been well documented and most of the study pertains to the effect of salinity, different irrigation regimes or diurnal variation. Sharma *et al*. (2015) however, in a study on the physiology of grapefruit cultivars on different rootstock observed significant variation in RWC with higher values in scion leaf of Red blush on rough lemon. Machado *et al*. (2010) evaluated the effect of low nocturnal temperatures under controlled conditions on Valencia orange scions grafted on Rangpur lime and Citrumello rootstock. They observed a decrease in leaf CO_2 assimilation, stomatal conductance, mesophyl conductance and CO_2 concentration in plants grafted on both the rootstock but was more severe in plants grafted on Rangpur lime rootstock.

Chlorophyll contents: Plant growth and photosynthetic behavior of young orange trees grafted on different rootstocks was investigated. Results revealed that there was a significant effect of different rootstocks on photosynthetic pigments in the orange leaves due to which varying activity of photosynthesis was recorded in orange trees (Cimen *et al*., 2014). There exists an evident difference of photosynthetic activity and chlorophyll fractions between different rootstocks (Gonzatto, 2011). Photosynthesis and degree of carbon assimilation in plants in day hours of a year is a decisive factor in plant vigor and productivity (Lawlor, 1995). Over all tree growth and yield capability of scion cultivars grafted on different rootstocks is determined by translocation and movement of carbohydrates from source (leaves) to sink (reproductive organs). Moreover, compatibility between rootstock and scion plays a key role in movement of carbohydrates and other important molecules between leaves and roots (Goldschmidt, 1999).

Performance of orange trees grafted on different rootstocks was evaluated with the objective to check the effect of different rootstocks on chlorophyll fractions and other leaf gas exchange parameters in calcareous soil. Varying amount of chlorophyll *a* and chlorophyll *b* in orange trees was recorded on different rootstocks. Orange trees grafted on Carrizo citrange rootstock had the highest transpiration rate owing to higher degree of stomatal conductance. Non-significant effect of different rootstocks on net photosynthetic rate was also recorded. But highest photosynthetic activity in the leaves of scion cultivar grafted on rootstock F-A5 showed tolerance of this rootstocks against the calcareous conditions of the soil (Gonzalez-Mas *et al*., 2009)

Phytohormones concentration: Rootstocks also influence the phytoharmones concentration in scion cultivars which ultimately affects the overall tree health and yield (Fallahi and Rodney, 1992). 'Canton Lemon' rootstock gave high yield of 'Shatangju' mandarin by increasing the cell proliferation rate during the phase of ripening. Qureshi *et al*., (2022) found that rootstocks influence the synthesis and translocation of plant hormones due to which leaf gas exchange, physiology of scion, vigor, and yield of scion cultivar are manipulated. High concentration of IAA, GA3, and ZT in Kinnow mandarin was recorded when grafted on *Poncirus trifoliata* and Fraser hybrid rootstocks.

The differences which were observed in fruit sizes on different rootstocks can be attributed to high concentrations of auxins in fruits which were grafted on cantonal rootstock. AUX-1 upregulation was responsible for different levels of auxins (Liu *et al.,* 2015). Concentrations of auxins and gibberelins in scion portion and leaves depends upon the vigor of rootstocks and concentration of phytoharmones in rootstocks (Tuzcu *et al.,* 2004). The largest tree size of

`Shatangju 'mandarins was obtained from rootstock 'Canton Lemon' and 'Grof lemon' due to higher levels of phytoharmones in that rootstock, and the lowest tree sizes was obtained from the 'Red Mandarin' and 'Fragrant Orange' rootstocks due to lower concentration of phytohormones in that rootstock (Liu *et al*., 2017).

Effect of rootstocks on carbohydrates concentration of citrus: Previously a lot of work has been done to investigate the effect of different rootstocks on all vegetative and reproductive aspects of citrus tree (Bassal, 2009; Forner-Giner *et al*., 2003). It was thought that there exists a specific mechanism which is responsible for the manipulations in different scion cultivars grafted on different rootstocks. Distribution of carbohydrates between source to sink is largely responsible for differences in yield capability of different scion cultivars. Rootstocks exert a great influence on carbohydrates translocation from leaves to other parts, therefore, responsible for variations in vegetative and reproductive aspects of different scion verities (González-Mas *et al*., 2009).

Carbohydrates are essential for many important processes of plants. There is complete dependence of deciduous trees on carbohydrates reserves for an early spring growth and bud burst stage. Presence of carbohydrates in old leaves make them able to be active photosynthetically even at old age. These carbohydrates reserves acts as back up energy supply unit in conditions of less photosynthesis activity (Bustan and Goldschmidt, 1998; Goldschmidt, 1999).

Effect of rootstock on fruit production and quality: Talking about fruit yield and quality of citrus, it is well discussed that role of rootstock is important in reproductive capability and vegetative vigor of citrus (Demirkeser *et al.*, 2005). Delta and 'Lana Late' cultivars of orange were grafted on rootstocks and compatibility was checked by observing average fruit yield and physico-chemical quality of fruits at three crop maturity stages. Citrumelo was harmful rootstock for both shoots, while 'GouTou' rootstock had low rate of compatibility and was harmful to Delta as well. Sour orange rootstock showed the high level of compatibility with Delta (Maria and Marios, 2017). Similarly, Ali (2002) observed the effect of different rootstocks on fruit quality and reported that maximum percentage of juice and the best skin color of Fremont were found on sour orange rootstock, while maximum TSS was found on Carrizo citrange rootstock. 'Troyer citrange', 'Cleopatra mandarin' and '*Poncirus trifoliata'* are some important rootstocks which influence the yield and quality of citrus fruits (Giner *et al*., 2008). These rootstocks were grafted with Washington Navel orange and yield and fruit quality. Troyer citrange showed the highest accumulative yield and the largest fruit size. *Poncirus trifoliata* produced semi dwarfing trees of Washington navel. In general scenario the performance of all the three rootstocks was satisfactory and it can be concluded that these three rootstocks can be used commercially for high yield and better quality citrus (Georgiou, 2000). In Texas an experiment was established to find out a replacement rootstock of sour orange. The trial was established by using ten rootstocks, i.e. 'Troyer Citrange', 'Carrizo citrange', 'Swingle citrumello', 'C-35', 'African shadow', 'C-22', 'C-146', 'C-57' and Sour Orange'. 'Rio Red' cultivar of grapefruit was used as a scion. The results showed that all the plants on C-35 and Swingle Citrumello dried and then died gradually. While maximum yield was obtained on Carrizo citrange and C-22 rootstocks because of their resistance to CTV. The impact of different rootstocks on overall yield, physico-chemical quality of fruit and tree size of 'Valencia' orange in Florida citrus orchards revealed that 'Sun Chu Sha' and 'Coleptera mandarin' undergoes best performance over other rootstocks. Speaking of tree survival and fruit productivity of individual trees, the performance of 'Cleopatra mandarins' was particularly good. This rootstock is not used as a commercial rootstock (Georgiou, 2009).

Production: Yield of Kinnow was maximum on Jatti Khatti rootstock closely followed by Karun Jamir and Estes Rough lemon and minimum yield was recorded on Cleopatra rootstock (Sharma *et al.,* 2002). Likewise, Brown (1920) while working at Peshawar reported significant difference in yield of Malta common on Rough lemon, Sweet lemon, Sour orange, and Citron rootstocks. Similarly, Sharma *et al.* (2002) found that out of four rootstocks studied over period of twenty years using Campabell Valencia as scion, fruit production on Jatti Khatti was the highest followed by Troyer citrange. Similar study was carried out by Al-Jaleel *et al.* (2005) who tried seven rootstocks namely *Citrus macrophylla*, Volkamer lemon, Cleoptara mandarin, Amblycarpa, Rough lemon, *Citrus taiwanica* and sour orange for Allen Eureka lemon and reported that highest mean yield on Macrophylla and Vlokamer lemon whereas, trees on sour orange were the least productive. Likewise, Georgiou (2002) reported that after eleven years of observations Rough lemon and Rangpur lime were the best rootstock for the fruit production of Clementine mandarin at Nicosia in Cyprus. Hussain *et al.* (2013) studied performance of Common clementine on nine rootstocks over a period of eleven years and found that trees on Carrizo citrange were most productive on Da Hang Pao mandarin and Gou Tou sour orange were the least productive. Likewise, Smith *et al.* (2004) evaluated Ellendale mandarin on seven rootstocks in Australia. Maximum yield was recorded on Lockyer Rough lemon while low yield was observed on Emperor mandarin rootstock. In Egypt, Marisol clementine was evaluated on four rootstocks. Maximum yield was obtained on Sour orange while poor performance of Cleopatra mandarin was recorded (Bassal, 2009). Similarly, Hilgeman (1975) compared the yield of seven Valencia oranges on four rootstocks. The trees were planted at three different locations in 1959. Up to 1966 trees on Rough lemon rootstock had the highest yield. Between 1968 and 1971 no difference in yield existed in trees on Rough lemon and Willow leaf mandarin rootstocks. However, the lowest yield was reported from trees

on Cleopatra mandarin. Under Cyprus conditions out of eleven rootstocks tested for Nova mandarin, sweet lime was judged as the best whereas, Swingle citrumelo and Troyer citrange as low yielding rootstocks (Georgiou, 2000). Likewise, Tazima *et al.* (2013) found that Swingle Citrumello rootstock induced better growth and high yield in Satsuma mandarin when grafted on it during the duration ranging from 2003 to 2011. In contrast, Okitsu satsuma mandarin on Volkamer lemon resulted in the lowest yield during the entire experimental period. Bitters (1960) evaluated the performance of Valencia orange on twenty five rootstocks planted at California. Early and good yield was obtained on lemon and lime rootstocks while, trees on mandarin group were slow in come into bearing. Maximum yield was recorded from trees on Alemow (*C. Macrophylla*) followed by *C. volkameriana* and Rangpur lime. Similarly, Hutchison (1978) found that out of twenty two rootstocks studied over a period of twelve years using Valencia orange scion, fruit production on Rough lemon was the highest followed by Troyer citrange. Likewise, Chohan *et al.* (1978) tried four rootstocks namely Jatti Khatti, Karna Khatta, Troyer and Carrizo for Kinnow and reported the highest mean yield on Jatti Khatti followed by Karna Khatta. In South Brazil Oneco mandarin was evaluated on six rootstocks out of which, trees on Swingle consistently had the highest yield than those on other rootstocks and the lowest cumulative yield was obtained for plants budded onto Flying dragon (Gonzatto *et al.*, 2011). Similarly, McCarty *et al.* (1974) compared the fruiting of Campbell Valencia on Troyer and Carrizo citranges in California and found that the yield on Carrizo was higher than on Troyer rootstock. Likewise, Stenzel and Neves (2004) from Maringa, Brazil found that the yield performance of Tahiti lime on seven rootstocks was fluctuated. Under same conditions and cultural practices varying yield on different rootstocks was recorded. Wutscher (1978) reported the result of a trial evaluating hundred rootstocks for thirty years. The highest mean yield of red grapefruit was obtained on Karna Khatta. Similarly, Stenzel *et al.* (2003) found that among seven rootstocks, trees on C13 citrange had the highest cumulative yield, but differed significantly only from Trifoliate orange. Likewise, Ofosu-

Effect of rootstocks on various fruit quality attributes: The rootstocks are known to have a distinct impact on tree vigour and nutrient uptake, which in turn, have direct relation with several parameters of fruit quality.

Physical Quality: Varying results with respect to effect of rootstock on fruit size have been reported by different workers. Constantin *et al*, (1979) working in Louisiana found that both Satsuma and Navel on Troyer or Carrizo citranges produced the heaviest fruits in comparison with other rootstocks such as Rough lemon, sour orange, grapefruit, Sampson tangelo or trifoliate orange. Fruits of Shamouti orange on the Rough lemon group, Palestine sweet lime and Volkamer lemon group gave the largest and heaviest fruit (Georgiou and Georgiou 1999).

Rootstocks have effect on fruit weight and size. Fruits of varying sizes from large to small were harvested when Okitsu mandarin was grafted on different rootstocks. Larger sized fruits were harvested from Orlando tangelo (Aviles *et al.* 2010). Qureshi *et al.*, (2021) found that Fraser hybrid rootstock proved to be best rootstock to enhance the biochemical quality of Kinnow. Maximum fructose, sucrose and glucose in kinnow juice were recorded from Fraser hybrid rootstock followed by *Poncirus trifoliata*.

Likewise, Stenzel and Neves (2004) found that rootstocks have no effect on fruit size of tahti lime. Simlarly, Fallahi and Rodney (1992) stated that the fruit weight of Fairchild mandarin on Taiwanica was higher than on other rootstocks. Likewise, Ahmad *et al.* (2007) reported that Kinnow mandarin had the maximum fruit weight on Volkamaer lemon followed by Brazilian sour rootstock whereas, trees on Carrizo citrange resulted in the minimum fruit weight. Tazima *et al.* (2013) from Brazil reported that fruit weight was influenced by rootstocks, trees grafted on to C-13, Carrizzo citrange, and Sunki mandarin produced the largest fruit. In a similar study, Navelina orange out of fourteen different rootstocks produced the heaviest fruits on Volkamer lemon and C-35 citrange rootstock (Giner *et al.*, 2003). Likewise, Bassal (2009) working in Egypt found that Marisol Clementine when budded on to four rootstocks. In another study, Filho *et al.* (2007) reported that fruit weight of Fallglo and Sunburst mandarins was not significantly influenced by rootstocks. However, according to the results of Smith *et al.* (2004) Ellendale mandarin budded on Lockyer had significantly heavier fruits than those budded on other rootstocks. Similarly, Macrophylla and Volkamer lemon rootstocks tended to produce the heaviest fruit of Allen eureka lemon as compared with those budded on other rootstocks (Al-Jaleel *et al.*, 2005). Likewise, Sharma *et al.* (2002) reported that the heaviest fruit of Kinnow mandarin were produced on Jatti Khatti rootstocks under arid- irrigated region of Punjab.

Biochemical parameters of fruit: Research conducted by Yonemoto *et al.* (2004) showed that Shirakawa satsuma on Flying dragon had higher soluble solids in comparison to those on *P trifoliata*. Similarly, Flying dragon trifoliate imparted better fruit quality and higher tolerance to citrus variegated chlorosis (CVC) to Folha Murcha trees (Aviles *et al.*, 2011). Likewise, Fallahi and Rodney (1992) found that Fairchild fruit from trees on Carrizo citrange had significantly higher soluble solids than those on Rough lemon and Volkamer lemon. Similarly, many research indicated that Orlando tangelo fruit from trees on Carrizo citrange also had a higher soluble solids and total acid than those on Rough lemon or Volkamer lemon (Fallahi *et al.*, 1991, Hutchison and Hearn 1977). In a similar study Castel *et al.* (2010) recorded lower soluble solids concentration on Volkamer lemon,

Rough lemon Macrophylla and Palestine sweet lime and higher values were recorded in trees on trifoliate orange and Valencia orange and Valencia rootstocks.

Musambi fruits on sweet lime stock contained less vitamin C than on Karna Khatta and Florida Rough lemon rootstock (Singh 1961). Likewise, Seville kimb (sour orange) under Pakistan conditions produced Valencia oranges with the highest ascorbic acid content and Rough lemon and Jullunduri Khatti with the lowest vitamin C content (Ali and Rahim 1961).

According to Tazima *et al.* (2013) the highest value for total soluble solids was observed in fruits from trees on trifoliate citrange. However, fruits of Okitsu mandarin on all rootstock represented total acid lower than one. Likewise, Georgiou (1999) found that fruit quality of Shamouti orange on Carrizo citrange was high and similar to that on sour orange. Similarly, fruits of Navelina orange on Volkamer lemon were the heaviest, however, juice content, brix and acid content were higher on sour orange. Excellent fruit quality and yield efficiency of Navelina orange was obtained on selection F&SSSA 5 and F&A 13 rootstocks (Giner *et al.,* 2003). Likewise, Bassal (2009) at Ismailia in Egypt recorded the highest total soluble solids in fruits on Carrizo citrange and the lowest on sour orange. The highest juice acidity was detected on sour orange. According to work of Filho *et al.* (2007) Rangpur lime and Cleopatra mandarin rootstocks were suitable rootstocks for Fallglo mandarin which induce precocious bearing, high juice content and good fruit external appearance. Kinnow mandarin on Cleopatra mandarin produced the highest soluble solids concentration and less vitamin C than those on Pectinifera (Sharma *et al.,* 2002). Similarly, Georgiou (2002) reported that Swingle citrumelo significantly increased the juice content and sour orange induced the highest brix value for Clementine mandarin. Likewise, Smith *et al.* (2004) concluded Troyer as the best rootstock for Ellendale mandarin. In terms of fruit quality trees on Troyer produced superior brix levels, high juice content and thin rind. Similarly, Al-Jaleel *et al.* (2005) reported that Allen Eureka lemon fruits had the highest soluble solids concentration on sour orange, Cleopatra mandarin and Amblycarpa rootstocks, whereas, higher acid content on Cleopatra mandarin and Amblycarpa. In another experiment Sharma *et al.* (2002) found the highest concentration of soluble solids in fruits of Campabell Valencia on Troyer and Carrizo rootstocks. Likewise, Hussain *et al.* (2011) reported the highest concentration of total soluble solids and acidity in Common clementine on Holansis trifoliate orange and AA18 trifoliate orange.

Conclusion: It is concluded that rootstock have capability to modulate and alter the various domains of a citrus plant such as resistance against biotic and abiotic stresses, vegetative growth, physiological growth, reproductive growth and fruit quality. There are specific rootstocks for different agro-ecological zones which performs better under those climatic conditions. Use of different rootstocks according to the compatibility with scion cultivar may help in improving the fruit production and quality of citrus.

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REFERENCES

Ahmed, W., M. Pervez, M. Amjad, M. Khalid, C. Ayyub and M.A. Nawaz. 2006. Effect of stionic combination on the growth and yield of kinnow mandarin (citrus reticulata blanco). Pakistan Journal of Botany 38:603.

Ahmed, W., M.A. Nawaz, M.A. Iqbal and M. Khan. 2007. Effect of different rootstocks on plant nutrient status and yield in kinnow mandarin (citrus reticulata blanco). Pakistan Journal of Botany 39:1779-1786.

Al-Jaleel, A. and M. Zekri. 2003. Effects of rootstocks on yield and fruit quality of'parent washington navel'trees. Paper read at Proceedings of the Florida State Horticultural Society.

Al-Jaleel, A., M. Zekri and Y. Hammam. 2005. Yield, fruit quality, and tree health of 'allen eureka'lemon on seven rootstocks in saudi arabia. Scientia horticulturae 105:457-465.

AL-Wailli, F.M. 2016. Effect of soaking seeds Citrusaurantium and Citrus limonumat different concentrations of licorice extract on the percentage of germination and growth of seedlings. Baghdad Science Journal 13:419-424.

Araujo C M, H.D.O. Vasconcellos and L.B. Batista. 1972. The influence of various rootstocks on fruit quality in the Pera orange (C sinensis). University Federal Rio de Janerio 2:35-45.

Araujo, F., A. Salibe and G. Filhi. 1998. Macronutrient concentration in leaves of scion as affected by different roots. Revista Boasi Leira 20:7-14.

Ashraf, M.Y., M. Yaqub, J. Akhtar, M.A. Khan, M. Ali-Khan and G. Ebert. 2012. Control of excessive fruit drop and improvement in yield and juice quality of kinnow (citrus

deliciosa x citrus nobilis) through nutrient management. Pakistan Journal of Botany 44:259-265.

Ateeq, M., M. Mubeen, S. Bashir, R.T. Bajwa, H.M.I. Arshad, A. Abbas and M.C.Z. Romano. 2023. Etiology and management of citrus Melanose disease in Pakistan: A review. Phytopathogenomics and Disease Control 2:29-36.

Bassal, M. 2009. Growth, yield and fruit quality of 'marisol'clementine grown on four rootstocks in egypt. Scientia Horticulturae 119:132-137..

Castle, W. 1980. Citrus rootstocks for tree size control and higher density plantings in florida. Paper read at Proceedings of the Florida State Horticultural Society.

Castle, W. S. 1987. Citrus rootstocks. Pp 361-99. John Wiley and sons, New York.

Castle, W.S. 1987. Citrus rootstock, p. 361-399. In: R.C. Rom and R.F. Carlson (eds.), Rootstock for fruit crops. Wiley, New York.

Castle, W.S. 2010. A career perspective on citrus rootstocks, their development, and commercialization. HortScience 45:11-15.

Castle, W.S., J.C. Baldwin and R.P. Muraro. 2007. 'Hamlin'orange trees on flying dragon trifoliate orange, changsha mandarin, or koethen sweet orange x rubidou x trifoliate orange citrange rootstock at three in-row spacings in a flatwoods site.

Castle, W.S., J.C. Baldwin, R.P. Muraro and R. Littell. 2010. Performance of 'valencia'sweet orange trees on 12 rootstocks at two locations and an economic interpretation as a basis for rootstock selection. HortScience 45:523-533.

Cimen, B., T. Yesiloglu, M. Incesu and B. Yilmaz. 2014. Growth and photosynthetic response of young 'navelina'trees budded on to eight citrus rootstocks in response to iron deficiency. New Zealand journal of crop and horticultural science 42:170-182.

Continella, A., C. Pannitteri, S. La Malfa, P. Legua, G. Distefano, E. Nicolosi and A. Gentile. 2018. Influence of different rootstocks on yield precocity and fruit quality of 'tarocco scirè'pigmented sweet orange. Scientia horticulturae 230:62-67.

Dubey, A. and R. Sharma. 2016. Effect of rootstocks on tree growth, yield, quality and leaf mineral composition of lemon (citrus limon (l.) burm.). Scientia horticulturae 200:131-136.

FAO . 2021. Food and agricultural organization, Available online with updates at http:// www. fao. org/ faost at/ en/# data/ QC

Erdal, I., M.A. Askin, Z. Kucukyumuk, F. Yildirim and A. Yildirim. 2008. Rootstock has an important role on iron nutrition of apple trees. World Journal of Agricultural Sciences 4: 173-177.

Fallahi, E. and D.R. Rodney. 1992. Tree size, yield, fruit quality, and leaf mineral nutrient concentration offairchild'mandarin on six rootstock. Journal of American Society of Horticultural Sciences 117:28-31.

Forner-Giner, M., A. Alcaide, E. Primo-Millo and J. Forner. 2003. Performance of 'navelina'orange on 14 rootstocks in northern valencia (spain). Scientia Horticulturae 98:223-232.

Forner-Giner, M., J. Rodriguez-Gamir, B. Martinez-Alcantara, A. Quiñones, D.J. Iglesias, E. Primo-Millo and J. Forner. 2014. Performance of navel orange trees grafted onto two new dwarfing rootstocks (forner-alcaide 517 and forner-alcaide 418). Scientia Horticulturae 179:376-387.

Forner-Giner, M.A., E. Primo-Millo and J.B. Forner. 2009. Performance of forner-alcaide 5 and forner-alcaide 13, hybrids of cleopatra mandarin x poncirus trifoliate, as salinity-tolerant citrus rootstocks. Journal of the American Pomological Society 63:72.

Georgiou, A. 2000. Performance of 'nova'mandarin on eleven rootstocks in cyprus. Scientia Horticulturae 84:115-126.

Georgiou, A. 2002. Evaluation of rootstocks for 'clementine'mandarin in cyprus. Scientia Horticulturae 93:29-38.

Georgiou, A. 2009. Evaluation of rootstocks for the cyprus local lemon variety 'lapithkiotiki'. Scientia horticulturae 123:184-187.

Georgiou, A. 2009. Evaluation of rootstocks for the cyprus local lemon variety 'lapithkiotiki'. Scientia horticulturae 123:184-187.

Giner, M.A., M.B. Baliu, J. Torrens and J.B. Forner. 2008. Performance of Washington Navel Orange grafted on three rootstocks. Proceedings of International Society of Citriculture 11:233.

Goldschmidt, E.E. 1999. Carbohydrate supply as a critical factor for citrus fruit development and productivity. HortScience 34:1020-1024.

González-Mas, M.C., M.J. Llosa, A. Quijano and M.A. Forner-Giner. 2009. Rootstock effects on leaf photosynthesis in 'navelina'trees grown in calcareous soil. HortScience 44:280-283.

Gonzatto, M.P., A.P. Kovaleski, E.C. Brugnara, R.L. Weiler, I.A. Sartori, J.G.d. Lima, R.J. Bender and S.F. Schwarz. 2011. Performance of'oneco'mandarin on six rootstocks in south brazil. Pesquisa Agropecuária Brasileira 46:406-411.

GOP. 2013-14. Pakistan Economic Survey. Finance Division, Editor. Economic Advisor`s Wing: Islamabad GOP. 2015. Pakistan Economic Survey. Finance Division, Editor. Economic Advisor`s Wing: Islamabad.

GOP. 2019. Agriculture Statistics of Pakistan. Ministry of Food, Agriculture and Livestock, Islamabad, Pakistan.

Hussain, S., F. Curk, M.A. Anjum, O. Pailly and G. Tison. 2013. Performance evaluation of common clementine on

various citrus rootstocks. Scientia horticulturae 150:278-282.

Josan, J. and S. Thatai. 2008. Studies on the evaluation of rootstocks for kinnow mandarin under north indian conditions. Indian Journal of Horticulture 65:332-334.

Jover, S., B. Martínez-Alcántara, J. Rodríguez-Gamir, F. Legaz, E. Primo-Millo, J. Forner and M. Forner-Giner. 2012. Influence of rootstocks on photosynthesis in navel orange leaves: Effects on growth, yield, and carbohydrate distribution. Crop science 52:836-848.

Kakade, V., A. Dubey and R. Pandey. 2014. Comparative efficacy of different triazole compounds as nacl stress protectants in kinnow budded on salt susceptible rootstock jatti khatti. International journal of fruit science 14:284-296.

Liu, X., J. Li, M. Huang and J. Chen. 2015. Mechanisms for the influence of citrus rootstocks on fruit size. Journal of agricultural and food chemistry 63:2618-2627.

Liu, X.-Y., J. Li, M.-M. Liu, Q. Yao and J.-Z. Chen. 2017. Transcriptome profiling to understand the effect of citrus rootstocks on the growth of 'shatangju'mandarin. PloS one 12:e0169897.

Machado, D.F.S.P., E.C. Machado, R.S. Machado and R.V. Ribeiro. 2010. Effects of low night temperature and rootstocks on diurnal variation of leaf gas exchange rates and photochemical activity of'valência'sweet orange plants. Revista Brasileira de Fruticultura 32:351-359.

Marathe, R., R. Sonkar, L. Ram and S. Singh. 2006. Nutrient uptake, canopy volume and yield of nagpur mandarin as affected by different rootstocks. Indian Journal of Horticulture 63:372-375.

Maria, G. and C. Marios. 2017. Rootstock-modulated yield performance, fruit maturation and phytochemical quality of â lane lateâ and â deltaâ sweet orange. Scientia horticulturae.

Qureshi, M.A., M.J. Jaskani, A.S. Khan, M.S. Haider, W. Shafqat, M. Asif and A. Mehmood. 2021. Influence of different rootstocks on physico-chemical quality attributes of kinnow mandarin. Pakistan Journal of Agricultural Sciences 58:929-935.

Qureshi, M.A., M.J. Jaskani, A.S. Khan and R. Ahmad (2022). Influence of endogenous plant hormones on physiological and growth attributes of Kinnow mandarin grafted on nine rootstocks. Journal of Plant Growth Regulation 4:1254-1264.

Richardson, A., P. Mooney, P. Anderson, T. Dawson and M. Watson. 2003. How do rootstocks affect canopy development. Hort. Research, Kerikeri Research Center. NewZealand. htt://www. hortnet. co. nz/publications/science/richardson/rootc an. htm. Acces date. 7:05.

Savita, G.S.V. and A. Nagpal. 2012. Citrus diseases caused by phytophthora species. GERF bull biosci. 3:18-27.

Salman, O., A. Al-Hayany and K. Ibrahim. 2022 Assessment of the success of micro grafting clementine timing on sour orange. Iraqi Journal of Agricultural Sciences 53:825-832.

Salih, A.Y. and M.T. Al-Jeboory. 2023 August. Effect of Foliar Spray of Zinc and Irrigating with Smoking-Water on Growth of Citrus Rootstock C35. In IOP Conference Series: Earth and Environmental Science 1225:012019.

Shah, M.A. 2004. Citrus cultivation in nwfp. Paper read at Proceedings of the 1st International conference on citriculture.

Shahid, I., M. Chauhdry and M. Anjum. 1999. Effect of rootstock on leaf mineral composition and productivity of kinnow mandarin. International Journal of Agrculture and Biology 1:91-93.

Sharma, J., J. Josan and S. Thatai. 2002a. Effect of rootstocks on tree health, yield and quality of kinnow mandarin under arid-irrigated region of punjab. Indian Journal of Horticulture 59:373-377.

Sharma, J., J. Josan and S. Thatai. 2002b. Performance of kinnow mandarin on different rootstocks under arid-irrigated region of punjab. Indian Journal of Horticulture 59:266-269.

Sharma, J., S. Thatai and J. Josan. 2002c. Effect of different rootstock on tree vigour, yield and fruit quality of campbell valencia sweet orange. Indian Journal of Horticulture 59:135-139.

Sharma, R.M., A.K. Dubey and O.P. Awasthi. 2015. Physiology of grapefruit (citrus paradisi macf.) cultivars as affected by rootstock. The Journal of Horticultural Science and Biotechnology 90:325-331.

Smith, M.W., R.G. Shaw, J.C. Chapman, J. Owen-Turner, L.S. Lee, K.B. McRae, K.R. Jorgensen and W.V. Mungomery. 2004. Long-term performance of 'ellendale'mandarin on seven commercial rootstocks in sub-tropical australia. Scientia Horticulturae. 102:75-89.

Stenzel, N.M., C.S. Neves, J.C. Gomes and C.C. Medina. 2003. Performance of'ponkan'mandarin on seven rootstocks in southern brazil. HortScience 38:176-178.

Stenzel, N.M.C. and C.S.V.J. Neves. 2004. Rootstocks for'tahiti'lime. Scientia Agricola 61:151-155.

Swingle, W.T. 1967. The botany of citrus and its wild relations. The citrus industry 1:190-422.

Taiz, L. and E. Zeiger. 2002. Plant physiology: Sinauer associates.

Tazima, Z.H., C.S.V.J. Neves, I.F.U. Yada and R.P. Leite Júnior. 2013. Performance of'okitsu'satsuma mandarin on nine rootstocks. Scientia Agricola 70:422-427.

Tazima, Z.H., C.S.V.J. Neves, I.F.U. Yada and R.P. Leite Júnior. 2013. Performance of'okitsu'satsuma mandarin on nine rootstocks. Scientia Agricola 70:422-427.

Toplu, C., V. Uygur, M. Kaplankıran, T.H. Demirkeser and E. Yıldız. 2012. Effect of citrus rootstocks on leaf mineral composition of 'okitsu','clausellina', and

'silverhill'mandarin cultivars. Journal of plant nutrition 35:1329-1340.

Tsakelidou, K., X. Papanikolaou and E. Protopapadakis. 2002. Rootstock effects on the yields, tree and fruit characteristics of the mandarin cultivar 'clementine'on the island of rhodes. Experimental agriculture 38:351-358.

Tuzcu, O., B. Yildirim and T. Yesiloglu. 2004. Effect of different rootstocks and sectors on fruit yield and its distribution depending to the tree canopy. Paper read at 10th International Society of Citriculture Congress, Agadir, Morocco.

Tuzcu, Ö., M. Kaplankiran and M. Şeker. 1998. The effects of some citrus rootstocks on fruit productivity of some important orange, grapefruit, lemon and mandarin cultivars in çukurova region. Turkish Journal of Agriculture and Forestry 22:117-126.

Wutscher, H. and A. Shull. 1972. Performance of 13 citrus cultivars as rootstocks for grapefruit. American Society of Horticultural Sciences

Wutscher, H., N. Maxwell and A. Shull. 1975. Performance of nucellar grapefruit, citrus paradisi macf., on 13 rootstocks in south texas. Journal American Society for Horticultural Science.

Wutscher, H.K. and L.L. Hill. 1995. Performance ofhamlin'orange on 16 rootstocks in east-central florida. HortScience 30:41-43.